Diode-pumped vertical external cavity surface emitting laser at 1 μm

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We demonstrated a diode-pumped vertical external cavity surface emitting laser with simple plane-concave cavity. When the pump power at a wavelength of 811.6 nm is 1.5 W, the maximum output power is 40.4 mW at the wavelength of 1005.8 nm. The optical-optical conversion efficiency is 2.7%.

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The diode-pumped vertical external cavity surface emitting lasers (DP-VECSELs) are highly attractive light sources for applications in interconnections and optical communications due to their useful characteristics. The DP-VECSELs combine the approaches of diode-pumped solid-state laser[1,2] and semiconductor quantum well vertical cavity surface emitting lasers (VCSELs)[3], drawing on the advantages of both. They can overcome both the beam quality limitations of the edge emitting diode laser and power restrictions of current-injection surface emitting laser, and they also do not require wavelength stabilization of the pump power compared with solid state laser systems[4]. DP-VECSELs can offer watt-power-level circularly symmetric output beams and the potential of wide spectral range in the visible and near infrared ranges, also with attractive application in frequency-doubling[5], mode-locked[6,7], and single-frequency operation[8]. In this paper we report a DP-VECSEL with simple plane-concave cavity.

The scheme of the laser cavity is shown in Fig. 1. The cavity length is 46 mm. The pump source used in the experiments was a fiber-coupled laser diode with a core diameter of 100 μm and a numerical aperture of 0.22, the maximum output power of which is 1.5 W at a wavelength of 811.6 nm, and its spectrum is shown in Fig. 2. The output beam from the fiber end is focused onto the VECSEL chip with an angle of incidence of 45° by a coupling optics system including a pair of spherical lens having the same focus length of 11 mm. The VECSEL chip was mounted on an electricity-cooled copper heat sink. The heat sink was designed specially, small and convenient to modulate, which was maintained at the temperature of 12 °C. The VECSEL structure was grown by standard metal-organic chemical vapor deposition (MOCVD). It comprised three main components (Fig. 3): the Bragg reflector, the gain region, and the confinement window layer. VECSEL chip is composed of an $Al_{86}GaAs/GaAs$ Bragg reflector (13.5 pairs of quarter-wave layers), with a calculated reflectivity ($>$ 99.9%) at 1040 nm. The active region consists of 6 InGaAs quantum wells designed for emission at 1040 nm, surrounded by GaAsP barrier layers with a total thickness of $7\lambda/2$, which allow an efficient absorption of the pump radiation. However the actual central wavelength deviates towards shorter-wavelength for the preparation process. Finally, a window layer of AlGaAs was grown and the full structure was completed by a thin InGaP capping layer. The AlGaAs window layer prevents excited carriers escaping to the surface and

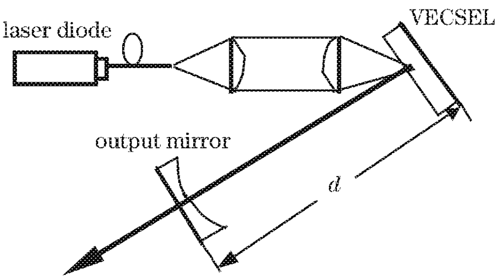

Fig. 1. Scheme of the VECSEL.

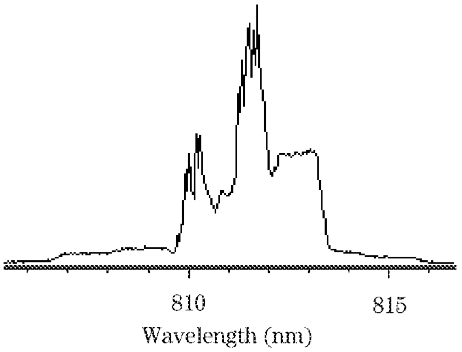

Fig. 2. Spectrum of the pump source.

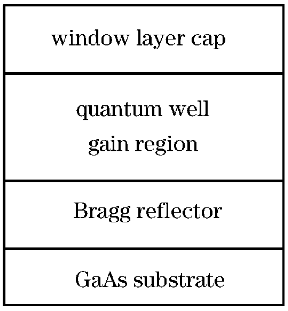

Fig. 3. The structure of VECSEL.

recombining nonradiatively. The output mirror with a radius of 50 mm is coated with high-reflection coating in a wide range of wavelength (>99.7% at 1005.8 nm.)

When the cavity length d is 46 mm, the laser threshold is about 300 mW at the temperature of 12 °C. We measured the wavelength with a spectrometer (SpectraPro-500i of Acton Research Corporation). As the pump power was increased, the main wavelength became longer. Because of the limitation of the pump power, we could only measure the variety in a small range. As the pump power was increased from 563 to 1500 mW, the main wavelength moved from 1003.7 to 1005.8 nm. The operation wavelength was broadened, and the refined operation wavelengths were also different with the pump power increasing, as shown in Fig. 4. Figure 5 shows the output power as a function of the diode laser pump power. When the pump power is 1.5 W, the maximum output power at 1005.8 nm is 40.4 mW. We increased the temperature of electricity-cooled copper heat sink from 12 °C, then the VECSEL gradually saturated and the laser ceased at the temperature of 20 °C. The output power has the trend of saturation (Fig. 5), which means that the thermal effect is severe in the experiment, and the intensity of pump and the cooling should be optimized. The beam profile was measured with a beam profiler (BeamCode, Coherent Instruments Division) as shown in Fig. 6, the intensity distribution is perfectly a Gaussian profile.

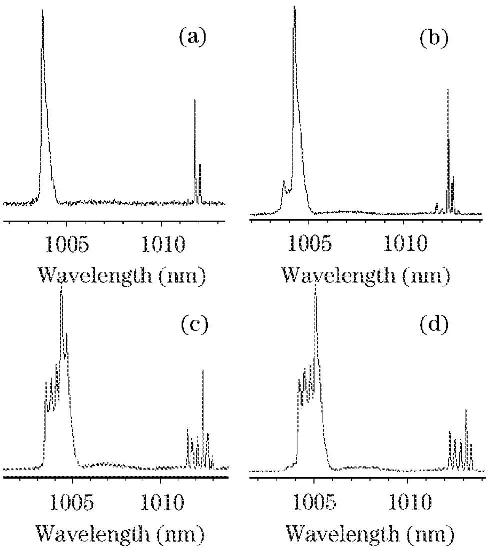

Fig. 4. Spectra of output laser with the pump power of 563 (a), 766 (b), 867 (c), and 1500 mW (d).

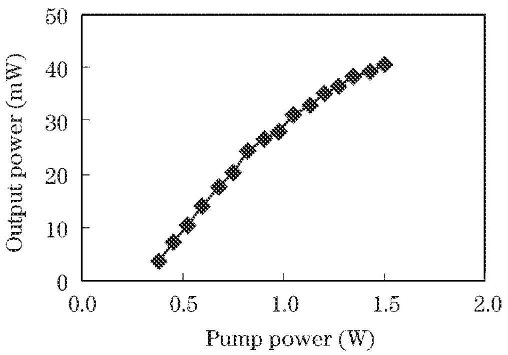

Fig. 5. Output power versus pump power.

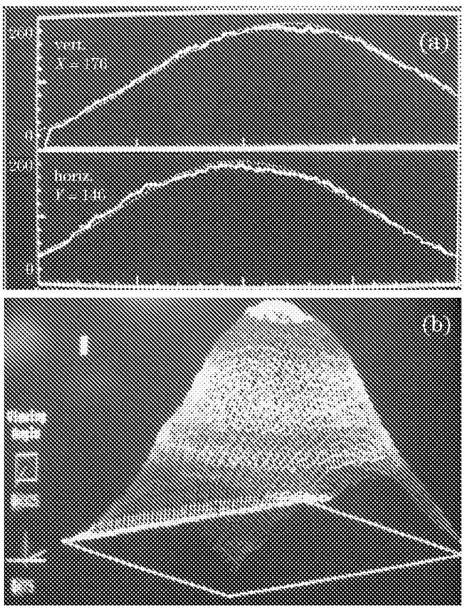

Fig. 6. (a): Intensity profile in X and Y axis. Dotted lines: standard Gauss-distributing; Solid lines: actual intensity distributing. (b): Three-dimensional intensity profile.

In conclusion, the DP-VECSEL with simple plane-concave cavity was achieved. When the pump power at a wavelength of 811.6 nm is 1.5 W, and the cavity length is 46 mm, the maximum output power was 40.4 mW at the chip temperature of 12 °C, optical-optical conversion efficiency is 2.7%, and the output power was limited by the low permeation of the output mirror (about 0.3 at 1005.8 nm). Further work includes the power scaling, intracavity frequency doubling, and mode locking.

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